In the Specification:

Please substitute the following new paragraphs beginning on page 7, line 23 and ending on page 15, line 11:

B1

The sectional view of Figure 1 illustrates the major components of a mass flow controller in accordance with the principles of the present invention. The mass flow controller 100 includes a thermal mass flow sensor assembly 102 and a valve assembly 104. The valve assembly 104 is connected to the mass flow controller housing 108 to control the rate of flow of gas in response to control signals generated by a mass flow sensor circuitry described generally in the discussion related to Figure 4. The mass flow controller 100 includes an inlet 106 for receiving a flow of gases to be metered. The process gas enters the mass flow controller though the inlet 106 and travels through the valve~~d~~ opening 110 to a bypass channel ~~112~~ 121. The valve 114 operates under control of the mass flow sensor and related circuitry to admit a precisely measured quantity of process gas into the inlet port 106, through the controller, and out the outlet port 116 for a processing application, such as may be employed in integrated circuit manufacturing. The bypass channel ~~112~~ 121 is connected to the inlet port 106 to receive and carry the stream of gas.

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A laminar flow element 118 rests within the channel ~~112~~ 121 and provides a pressure drop across the thermal mass flow sensor 102 and drives a portion of the gas through the sensor tube 120 of the thermal mass flow sensor 102. The mass flow sensor includes circuitry that senses the rate of flow of gas through the controller 100 and controls operation of the valve assembly ~~114~~ 104. The mass flow sensor assembly 102 is attached to a wall 122 of the mass flow controller that forms a boundary of the bypass channel ~~112~~ 121. Input ~~124~~ and output ~~126~~ apertures 124 and 126, respectively, in the wall 122 provide access to the mass flow sensor assembly 102 for a gas travelling through the mass flow controller 100. In this illustrative embodiment the mass flow sensor assembly 102 includes a base plate 128 for attachment to the wall 122. The base plate 128 may ~~de~~ be attached to the wall and to the remainder of the sensor assembly using threaded hole and mating bolt combinations, for example. Input ~~130~~ and output ~~132~~

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legs 130 and 132, respectively, of the sensor tube 120 extend through respective input ~~134~~ and output ~~136~~ apertures of the base_plate 128 and, through apertures 124 and 126~~,~~ of the mass flow controller wall 122.

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The mass flow sensor assembly includes top ~~138~~ and bottom ~~140~~ sections 138 and 140 that, when joined, form a thermal clamp 141 that holds both ends of the sensor tube active area (that is, the area defined by the extremes of resistive elements in thermal contact with the sensor tube) at substantially the same temperature. The thermal clamp also forms a chamber 142 around the active area of the sensor tube 120. That is, the segment of the mass flow sensor tube within the chamber 142 has in thermal communication with it two or more resistive elements 144, 146, each of which may act as a heater, a detector, or both. One or more of the elements is energized with electrical current to supply heat to the fluid as it streams through the tube 120.

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The thermal clamp 141, which is typically fabricated from a material characterized by a high thermal conductivity relative to the thermal conductivity of the sensor tube, makes good thermally conductive contact with the portion of the sensor tube just downstream from the resistive element 144 and with the portion of the sensor tube just upstream from the resistive element 146. _The thermal clamp thereby encloses and protects the resistive elements 144 and 146 and the sensor tube 120._ Additionally, the thermal clamp 141 thermally "anchors" those portions of the sensor tube with which it makes contact at, or near, the ambient temperature. In order to eliminate even minute errors due to temperature differentials, the sensor tube may be moved within the thermal clamp to insure that any difference between the resistance of the two coils is due to fluid flow through the sensor tube; not to temperature gradients imposed upon the coils from the environment. In accordance with the principles of the present invention, the chamber that encloses the sensor tube, the thermal clamp in this illustrative embodiment, makes contact with the mass flow controller through a thermal ground 148. The thermal ground may be formed, as illustrated, between the thermal clamp 141 and the base_plate 128 and/or between the base_plate 128 and the controller-housing wall 122, for example. The thermal ground may be integral to the controller-housing wall, to the base_plate, or to the thermal clamp, for example. Alternatively, the thermal ground may be a separately-

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formed thermally conductive element positioned between the thermal sensor assembly and the controller housing.

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In the illustrative embodiment of Figure 2 a heat sink 150 is attached in good thermal communication with the housing 152 of the valve assembly 104. Power dissipated by a solenoid in operation of the valve 114 may generate a significant amount of heat that might travel through the mass flow controller housing 108 and superimpose an external thermal gradient upon the sensor assembly 102. Such an external thermal gradient superimposed on the sensor resistive elements 144 and 146 would create an error in the determination of mass flow through the sensor tube. That is, since the thermal mass flow sensor relies upon the tendency of the fluid flowing through the sensor tube 120 to establish a thermal gradient to measure the mass of fluid flowing through the tube 120, an externally imposed thermal gradient would render a false reading. In this illustrative embodiment the heat sink 150 substantially envelopes and conducts heat away from the ~~valve assembly body~~ housing~~152 and conducts heat away from the body~~ 152.

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In an embodiment in which the heat sink 150 is open to the atmosphere, features such as fins (not shown) may be added to the heat sink to increase the ~~transport~~ transfer of heat away from the valve assembly body 152 and away from the sensor assembly 102. That is, fins may be added to one or more sides of the heat sink 150 not facing the sensor assembly 102 in order to increase convective and radiant heat ~~transport~~ transfer away from both the sensor assembly 102 and the valve assembly 104. In an illustrative embodiment described in the discussion related to Figures 5 and 7, the heat sink 150 extends to make thermally conductive contact with a controller housing that encloses the sensor 102 and valve 104 assemblies. In such an embodiment a smooth-surfaced heat sink 150 provides greater surface contact with the controller housing and thereby provides a more substantial thermally conductive path for dissipation heat from the valve assembly 104. A mass flow controller in accordance with the principles of the present invention such as presented in the illustrative embodiment of Figure 3 employs both a heat sink 150 and thermal ground 148 to substantially eliminate thermal gradients that might otherwise impair operation of the mass flow sensor 102.

37 Figure 4 illustrates in greater detail an embodiment of a mass flow sensor in accordance with the principles of the present invention. The bypass tube ~~112~~121, laminar flow element 118, upstream resistive element 146 and downstream resistive element 144 are as previously described. The arrangement of the thermal clamp 141, including top 138 and bottom 140 portions, and its thermally conductive communication with the sensor tube 120 is illustrated in greater detail here. The ~~broken lines of the~~ sensor tube 120 ~~indicate that the tube~~ is substantially surrounded and in conductive thermal contact with the thermal clamp 141 around its entire circumference at each end of its operational segment. The operational segment of the sensor tube is defined for illustrative purposes as that segment of the sensor tube disposed between the upstream 154 and downstream 156 legs of the thermal clamp.

38 One end 119 of the portion of the bypass tube ~~112~~121 that is coupled to the sensor tube defines an input ~~port~~ and the other end of the portion of the bypass tube ~~112~~121 that is coupled to the sensor tube defines an output ~~port 121~~123 so that in operation fluid ~~may~~ flows from the input ~~port~~ to the output ~~port~~ portions in a downstream direction indicated by arrows shown in Figure 4. The laminar flow element 118 is disposed within the bypass tube for restricting the flow of fluid through the tube. An upstream end of the sensor tube couples to the bypass tube between the input end portion 119 ~~port~~ and the laminar flow element 118. A downstream end of the sensor tube couples to the bypass tube between the laminar flow element 118 and the output portion 123~~, a~~. A fixed proportion of the total mass of fluid flowing from the input portion 119 to the output portion 123 flows through the sensor tube. The sensor tube may be of capillary dimensions and is fabricated from a material, such as steel, that is characterized by a relatively high thermal conductivity in comparison to the thermal conductivity of the fluid.

39 Each of the resistive elements 144 and 146 includes a thermally sensitive resistive conductor that is wound around a respective portion of the sensor tube 120, each successive turn of the conductors being placed close to the previous turn. Each of the resistive elements extends along respective portions of the sensor tube 120 along an axis ~~AX1~~ defined by the operational segment of the sensor tube 120. Downstream resistive

element 144 is disposed downstream of the resistive element 146. The elements abut one another or are separated by a small gap for manufacturing convenience and are electrically connected at the center of the tube. Each resistive element provides an electrical resistance that varies as a function of its temperature. _The temperature of each resistive element varies as a function of the electrical current flowing through its resistive conductor and the mass flow rate within the sensor tube. In this way, each of the resistive elements operates as both a heater and a sensor._ That is, the element acts as a heater that generates heat as a function of the current through the element and, at the same time, the element acts as a sensor, allowing the temperature of the element to be measured as a function of its electrical resistance._ The mass flow sensor 102 may employ any of a variety of electronic circuits, typically in a Wheatstone bridge arrangement, to apply energy to the resistive elements 146 and 144, to measure the temperature dependent resistance changes in the elements and, thereby, the mass flow rate of fluid passing through the tube 120. _Circuits employed for this purpose are disclosed, for example, in U.S. Patent 5,461,913, issued to Hinkle et al and U.S. Patent 5,410,912 issued to Suzuki, both of which are hereby incorporated by reference in their entirety.

In operation, fluid flows from the input portion 119 of the bypass tube 121 to the output portion ~~121~~ 123 and a portion of the fluid flows through the restrictive laminar flow element 118. _The remaining fluid flows through the sensor tube 120. _The circuit (not shown) causes an electrical current to flow through the resistive elements 144 and 146 so that the resistive elements 144 and 146 generate and apply heat to the sensor tube 120 and, thereby, to the fluid flowing through the sensor tube 120. _Because the upstream resistive element ~~146~~ 144 transfers heat to the fluid before the fluid reaches the portion of the sensor tube 120 enclosed by the downstream resistive element ~~144~~146, the fluid conducts more heat away from the upstream resistive element ~~146~~ 144 than it does from the downstream resistive element ~~144~~ 146. The difference in the amount of heat conducted away from the two resistive elements is proportional to the mass flow rate of fluid within the sensor tube and, by extension, the total mass flow rate through the mass flow rate controller from the input port through the output port. _The circuit measures this difference by sensing the respective electrical resistances and generates an output signal that is representative of the mass flow rate through the sensor tube.

B11 The base_plate 122 may be integral to the sensor assembly or it may be attached to the assembly through any of a variety of attachment means, such as threaded through-holes and bolts, for example. The base_plate 122 is configured to provide a thermal path between the sensor assembly 102 and the remainder of the mass flow controller 100 and to thereby maintain the average temperature of the sensor assembly 102 and the remainder of the mass flow controller at substantially the same average temperature. Additionally, the thermal path provided by the base_plate, through use of the thermal ground 148, is configured to substantially reduce or eliminate thermal gradients which might otherwise be imposed upon the mass flow sensor assembly through thermally conductive contact with the mass flow controller housing.

B12 In particular, the thermal ground 148 features a cross-sectional area that is significantly less than the cross sectional footprint of the sensor assembly 102. The cross-section of the thermal ground may have a circular, rectangular or other geometrical shape._ The thermal ground provides a thermal path that is sufficient to maintain the overall average temperatures of the mass flow sensor assembly and the remainder of the mass flow controller at substantially the same level.

B13 In this illustrative embodiment, the thermal ground 148 is located in an area of the sensor assembly that is substantially coincident with the midpoint of the flow sensor tube 120 and orthogonal to the flow axis ~~AX1~~ of the sensor tube 120. The position is chosen to ensure that no thermal gradient is imposed upon the sensor tube 120. However, other positioning arrangements are contemplated within the scope of the invention. For example, as described in greater detail in U.S. Patent 5,693,880 issued to Maginnis, Jr., which is hereby incorporated by reference in its entirety, the accuracy of a thermal flow sensor may be sensitive to the position of the tube/resistive element assembly with respect to the thermal clamp legs 156 and 154. In an illustrative embodiment, rather than shifting the sensor tube 120 in an effort at thermal balancing, the thermal ground 148 may be positioned to "zero out" minor differences due to positioning issues relative to the thermal clamp, such as discussed in U.S._Patent 5,693,880. In order to facilitate such balancing, the thermal ground 148 may include a captive shim, one or more slots for

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sliding attachment of the ground 148 relative to the lower section 140 of the thermal clamp or to the base_plate 128, for example.

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One measure of the effectiveness of the thermal ground at keeping the average temperature of the sensor assembly at substantially the same average temperature as the remainder of the mass flow controller is the lag time between a change in the average temperature of the controller and a corresponding change in the average temperature of the mass flow sensor assembly 102. The permissible lag time is a design choice that may affect the accuracy of mass flow readings. Given a permissible lag time (for given a temperature shift), a corresponding thermal flow figure may be computed. The thermal flow figure may then be used to determine the thermal conductivity and cross sectional area required for the thermal ground material. To minimize the possibility of the establishment of thermal gradients across the flow sensor housing, the cross sectional area of the thermal ground is minimized. That is, for a convenient structural material, such as Aluminum, the cross sectional area of the thermal ground must be large enough to eliminate temperature differentials between the thermal mass flow sensor assembly and the thermal mass flow controller housing, yet small enough to prevent the establishment of thermal gradients across the cross-section of the thermal ground. _In an illustrative embodiment, the ratio of cross sectional areas of the sensor assembly and thermal ground is at least two to one.

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The perspective view of Figure 5 provides an external view of the sensor assembly and valve assembly as previously described. The valve assembly includes a heatsink 150 that is formed to provide a substantial thermal path between the valve assembly 152,-_the heat_sink 150 and an external cover to be described in the discussion related to Figure 7. _The inlet ~~106~~-and outlet ~~116~~-ports 106 and 116 are as previously described. The sensor assembly 102 includes top ~~138~~-and bottom ~~140~~-thermal clamp components 138 and 140 attached to the wall of the controller assembly through the base plate 128._ The base_plate 128 is held in position with bolts 160. _Mass flow controller electronics (not shown) are attached to the controller with a metal flange 162. _Exterior surfaces of the heat_sink 150 make conductive contact with the interior surfaces of a controller enclosure. _In this illustrative embodiment, at least three exterior surfaces of

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the heat_sink make thermally conductive contact with the thermally conductive enclosure; which three exterior surfaces of the heat_sink will be apparent from examination of Figure 7.

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The perspective view of Figure 6 provides a more detailed exterior view of the sensor assembly 102. In this illustrative embodiment, the thermal ground 148 is of a rectangular cross-section orthogonal to the flow axis of the sensor tube and has been formed in the base_plate 128. The perspective view of Figure 7 illustrates a view of a mass flow controller assembly in accordance with the principles of the present invention in which a thermally conductive enclosure 164 envelopes the valve assembly and sensor assembly, as previously described. A heat_sink that makes conductive thermal contact with the valve assembly may also make thermal contact with the enclosure 164. The enclosure may also incorporate features, such as fins, to accelerate heat exchange between the enclosure's interior and exterior.